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Sleep deprivation, physical fatigue, and the perception of exercise intensity

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ABSTRACT

MYLES, WILLIAM S. Sleep deprivation, physical fatigue, and the perception of exercise intensity. *Med. Sci. Sports Exerc.*, Vol. 17, No. 4, pp. 580–584, 1985. This paper presents the results of three experiments to determine the effect of sleep deprivation and physical fatigue on ratings of perceived exertion (RPE) for exercise of short (30 s) and long (15–50 min) duration. In the first, 12 male subjects walked on a treadmill, 50 min every 3 h, at 28% of their $\dot{V}O_{2max}$ for 60 h without sleep. The RPE, recorded at the mid-point of each exercise bout, increased progressively with sleep loss. In the second experiment, when 12 female subjects performed ten 30-s bicycle exercise bouts before and after 54 h without sleep, there was no significant increase in RPE. In the third experiment, which examined the effect of physical fatigue on RPE, seven males performed two sets of ten 30-s bouts of cycle exercise before and after treadmill exercise at 70% of their $\dot{V}O_{2max}$ to voluntary exhaustion. In one set, RPE was recorded; in the other, power output was measured. During the treadmill running, increases in RPE were observed and attributed to fatigue. This same fatigue caused only small changes in RPE and power output for the cycle exercise. The combined data suggest that where the exercise is of several minutes' duration, RPE is increased by sleep deprivation and by physical fatigue. Where the exercise period is as short as 30 s, sleep deprivation has no effect and physical fatigue causes only a small change in the perception of exercise intensity.

SLEEP DEPRIVATION, PHYSICAL FATIGUE, EXERCISE DURATION, PERCEPTION OF EXERCISE INTENSITY

It is well established that periods of sleep deprivation up to 65 h cause a deterioration in mood and a decline in cognitive performance which increases with the amount of sleep lost (13,18,19,28). It is also accepted that well-learned or mainly physical tasks are the least sensitive to sleep deprivation (10). In contrast, the physiological systems regulating homeostasis in humans appear to be relatively unaffected by sleep loss (8,12,16,24). In particular, it seems that periods of sleep loss up to 65 h have little effect on exercise capacity, as evidenced by cardiovascular endurance and muscular strength (6,11,21,23,26). Exceptions to this generalization are studies by Copes and Rosentsweig (5), who showed that motor performance in ninth-grade students was adversely affected by 50 h of sleep loss, and Martin (14), who found that time to exhaustion for treadmill walking at 80% of $\dot{V}O_{2max}$ was decreased by 11% after 36h without sleep.

Subjective ratings of perceived exertion (RPE), using the Borg scale (3), appear to be one of the few exercise-related parameters affected by sleep deprivation. Martin (14) and Martin and Gaddis (15) have shown that periods of sleep deprivation lasting from 30–36 h caused an increase in RPE for submaximal exercise. In an earlier study, Soule and Goldman (25) examined the effect of 31 h of sleep deprivation on walking on a "self-paced" treadmill with loads of 15 to 30 kg carried on the back. They found that, while self-paced work rates were unchanged, higher RPE values indicated that the subjects found the work harder after sleep loss. In all of these studies the exercise period lasted several minutes; none of them reported RPE for short duration exercise.

This paper contains data from three experiments to determine the effect of sleep deprivation and physical fatigue on RPE for exercise of short (30 s) and long (15–50 min) duration. Two of these concern the effect of sleep deprivation, and the RPE data reported here represent only a small part of two larger studies of mood and cognitive performance (1,2,22,24). The third experiment was designed to resolve an apparent conflict between the RPE data from the first two experiments. It involved RPE measured before, during, and after a period of exhausting treadmill exercise.

METHODS

A summary of the protocols for Exeriments I, II, and III is provided in Table 1. In all three experiments, subjects signed a statement confirming their informed consent.

Experiment I. Twelve healthy male volunteers (see Table 2) went without sleep for 60 h beginning at 0900 hours. At least 24 h before the period of sleep deprivation and immediately after it ended, $\dot{V}O_{2max}$ was measured by a progressive treadmill protocol. In this protocol, speed was held constant at 13 $km \cdot h^{-1}$ and slope was increased 2% every 2 min to 8%, and thereafter

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TABLE 1. A summary of the protocols for Experiments I, II, and III.

Experiment	Sleep Loss	Details of the Protocol
I	60 h	RPE during treadmill walking at 28% $\dot{V}O_{2max}$ for 50 min every 3 h.
II	54 h	RPE during cycle exercise (ten 30-s bouts) before and after sleep deprivation.
III	—	RPE during treadmill running to exhaustion at 70% $\dot{V}O_{2max}$. RPE and power output during bicycle exercise (2 × ten 30-s bouts) before and after the treadmill run.

TABLE 2. Physical characteristics of the subjects.

Experiment	Sex	N	Age (yr)	Body Weight (kg)	$\dot{V}O_{2max}$ ($ml \cdot min^{-1} \cdot kg^{-1}$)
I	M	12	22.7 ± 0.6	72.6 ± 1.4	55.1 ± 1.2
II	F	12	21.5 ± 0.4	62.7 ± 2.0	45.5 ± 2.5
III	M	7	29.6 ± 1.7	75.3 ± 2.2	52.7 ± 1.2

Values are mean ± SE.

1% every 2 min to volitional fatigue. During the period of sleep loss, the subjects walked on a treadmill for 50 min every 3 h at an average of 28% of their initial $\dot{V}O_{2max}$. Oxygen consumption and heart rate were measured at the mid-point of each exercise session, and RPE was recorded at the same time using the scale developed by Borg (3). The time not spent walking on the treadmill was devoted to tests of mental performance with adequate breaks for meals, etc.

Experiment II. Twelve healthy female volunteers (see Table 2) went without sleep for 54 h commencing at 0900 hours. These subjects were sedentary and spent their time carrying out a continuous series of cognitive tasks with about 40 min of rest every 6 h. At least 24 h before the period of sleep deprivation and immediately after, $\dot{V}O_{2max}$ was measured. The protocol was a progressive cycle test (27) in which the subject pedalled at a constant speed of 60 $rev \cdot min^{-1}$. Starting at 60 W, the workload was increased by 30 W every 2 min until the subject was exhausted.

Response (R) cycle protocol was practiced by each subject once and repeated before and after the period of sleep deprivation. In the R protocol, the subject pedalled a Collins electrically braked cycle ergometer at 70 $rev \cdot min^{-1}$. Each subject performed two 30-s bouts of exercise at 100 and 180 W, separated by one minute of rest. This was followed by ten 30-s bouts at intensities of 100, 120, 140, 160, and 180 W, repeated, each separated by 1 min of rest. The subject was instructed to rate each bout on the Borg (3) scale as if it were unique and not to compare the level of exertion to previous bouts. The ten exercise intensities were presented in the same random order to all subjects on all three occasions. Ratings for the first two 30-s exercise bouts were used for additional practice and were not included in the mean calculated from the remaining ten.

Experiment III. The subjects were seven healthy male volunteers (see Table 2). On three occasions they practiced two cycle protocols, the first of which was identical to the R protocol used in Experiment II. In the second, called the Production (P) protocol, the subject was given two Borg scale ratings, 9 (very light) and 17 (very hard), 90 s apart. This was followed by a sequence of ten ratings (9, 11, 13, 15, and 17 repeated), one every 90 s. For each rating, the subject was asked to select an appropriate workload on a Monark cycle ergometer which had been modified so that he could adjust the belt tension without being aware of the workload he had selected. The pedalling speed was 70 $rev \cdot min^{-1}$, in time to a metronome. The subject was allowed 30 s to adjust the belt tension to his satisfaction, whereupon the workload was recorded by the investigator. The sequence of ten ratings were presented in the same random order to all subjects on all occasions. The first two workloads were used for practice, and the mean was calculated from the remaining ten.

At the practice sessions, the subject was introduced to the fatigue checklist (9), which asks him to rate himself against a list of ten descriptive phrases (e.g., "quite fresh"). He may indicate that he feels better than (2 pts), the same as (1 pt), or worst than (0 pt) each of the descriptors. Adding the points gives a fatigue score of 0 to 20, with zero indicating the most fatigued state possible.

On the experimental day, fatigue checklists were completed, and the R and P protocols were administered at 0900 hours. Afterwards, the subjects began a series of 15-min bouts of treadmill running at 70% of their $\dot{V}O_{2max}$ directly determined by a progressive treadmill test (27). Each exercise bout was separated by a 5-min rest period, during which the subject completed a fatigue checklist. Heart rate was measured by ECG every minute during the last 5 min and, in the final minute, the subject was asked to rate the exercise intehsity on the Borg scale (3). This sequence continued until the subjects had completed a total of 2 h of treadmill exercise or were unable to continue. After 20 min of rest, the R and P protocols were repeated.

Statistics. The data were analyzed by a paired *t*-test with the level of significance set at 5%. Values are expressed as means ± SE.

RESULTS

Experiment I. The 12 subjects walked on a treadmill at an average of 28% of their $\dot{V}O_{2max}$, for 50 min every 3 h, for 60 h without sleep. Oxygen consumption during treadmill walking averaged 1.04 $l \cdot min^{-1}$, and heart rate averaged 104 $beats \cdot min^{-1}$; neither parameter increased significantly as the period of sleep deprivation progressed. In contrast, RPE increased progressively with sleep loss. Table 3 indicates the average values for RPE

TABLE 3. Experiments I and II: RPE before and after sleep deprivation.

	RPE		
	Before Sleep Loss	After Sleep Loss	Significance
Experiment I (treadmill walking)	8.7 ± 0.2	11.2 ± 0.2	$P < 0.01$
Experiment II (R cycle protocol)	11.1 ± 0.3	11.5 ± 0.3	NS

Values are mean ± SE.
Values for Experiment I are the averages of ratings during the first and last 12 h of sleep deprivation. Values for Experiment II are the averages of ratings for ten 30-s exercise bouts.

TABLE 4. Experiment III: heart rate, RPE, and fatigue scores for the first and last 15-min bouts of treadmill running.

	First 15 min	Last 15 min	Significance
RPE	13.4 ± 0.4	17.4 ± 0.4	$P < 0.01$
Fatigue score	11.1 ± 1.1	5.7 ± 0.7	$P < 0.01$
Heart rate (beats · min^{-1})	162 ± 4	175 ± 4	$P < 0.01$

Values are mean ± SE. Heart rate is the average of the last 5 min of exercise; RPE was reported during the last minute of exercise, and the fatigue score was reported during the first minute of rest.

TABLE 5. Experiment III: RPE (R protocol), power output (P protocol), and fatigue score before and after treadmill running.

	Before Treadmill Running	After Treadmill Running	Significance
RPE	11.9 ± 0.5	12.6 ± 0.6	$P < 0.05$
Power output (W)	239 ± 11	224 ± 12	$P < 0.05$
Fatigue score	12.3 ± 0.6	9.4 ± 0.4	$P < 0.01$

Values are mean ± SE. Fatigue scores were recorded just before cycle exercise.

during the first and last 12 h of sleep deprivation. The $\dot{V}O_{2max}$ measured immediately after sleep deprivation was significantly decreased from pre-exposure values by an average of 5.3%.

Experiment II. Ratings of perceived exertion for 12 female subjects performing the R cycle protocol before and after 54 h of sleep deprivation (Table 3) showed no significant change. About two-thirds of the subjects increased their average RPE after sleep deprivation; the remainder did not change their rating or indicated a decrease. There was no significant change in $\dot{V}O_{2max}$ measured before and after the period of sleep deprivation.

Experiment III. The subjects performed the R and P cycle protocols before and after a fatiguing treadmill run. The average running time was 83 ± 12 min. Of the seven subjects, two completed a total of 120 min (eight 15-min bouts), and the rest stopped because they were unable to continue at from 45–105 min.

Average heart rate during the last 5 min of exercise rose with each successive 15-min bout of running and, after an initial delay, fatigue and RPE also increased. Table 4 shows the mean heart rates, RPE, and fatigue scores for the first and last bouts of running. All the subjects increased their heart rates and became fatigued (i.e., fatigue scores decreased); all subjects gave higher RPE values for the last exercise bout as compared to the first.

Table 5 shows RPE values (R protocol) and power output (P protocol) for cycle exericse before and after treadmill running. There was a small but significant increase in RPE and a similar decrease in power output, both attributable to the fatigue of running to exhaustion.

DISCUSSION

The effect of sleep deprivation and physical fatigue on RPE was investigated with three different experimental protocols. In addition, short (30 s) and long (15–50 min) exercise periods were compared to determine the influence of exercise duration. Although the protocols for the three experiments are dissimilar, none of the differences should negate the conclusions drawn from the combined data.

In experiment I the RPE during exercise was increased after 60 h of sleep deprivation. Since the exercise period was of relatively long duration (50 min) and was repeated every 3 h, there was some concern that the rise in RPE was due to the cumulative effects of exercise and not to any effect of sleep loss. Experiment II tested this possibility by administering the R protocol, in which the exercise duration was only 30 s, before and after 54 h of sleep deprivation. The results indicate that RPE was unaffected by sleep loss. This finding would appear to contradict those of other authors (14,15,25) who reported that RPE values for work periods of from 8–60 min, at intensities ranging from 25–80% of $\dot{V}O_{2max}$, were increased by 30–36 h of sleep deprivation.

One explanation for the different results in Experiments I and II may lie in the small decline in $\dot{V}O_{2max}$ (5.3%) observed in the first but not the second experiment. However, since exercise at 28% of $\dot{V}O_{2max}$ does not greatly stress the maximal power of the cardiovascular system, it seems unlikely that this small decrease in $\dot{V}O_{2max}$ can account for the marked increase in RPE (Table 3).

If the most likely explanation for the rise in RPE in Experiment I is the cumulative effects of exercise, it should be noted that there was no change in heart rate. A rise in heart rate at a constant exercise intensity indicates an increase in cardiovascular strain and is often accompanied by subjective sensations of fatigue (17). Perhaps the rise in RPE was due to increasing discomfort in leg muscles, joints, and feet. In retrospect, it might have been wiser to have used a differentiated ratings system such as that described by Pandolf (20) in all three experiments.

The rise in perceived effort with exercise duration

under control (no sleep deprivation) conditions is well documented. Edwards et al. (7) found that RPE (Borg scale) rose progressively as the work period in intermittent exercise was extended from 15 to 120 s. Cafarelli et al. (4) used magnitude estimation to demonstrate a similar effect of exercise duration on perceived effort at different cycle workloads. Cafarelli et al. (4) also showed that the rate of increase in perceived effort was itself a direct function of workload, suggesting fatigue as a likely stimulus for any increase in RPE during continuous exercise at a given intensity.

Although it must be considered as a speculation, it is possible that sleep deprivation somehow enhances the effect of exercise duration on RPE. In support is the observation that mood and cognitive performance were significantly degraded in Experiments I and II (1,2). It may be that these changes in mood contributed to the increase in RPE during treadmill walking in Experiment I. However, this assumes that similar mood changes in Experiment II had no effect on RPE for the short cycle exercise.

Experiment III was designed to resolve the conflict between the data from the two preceding experiments; in particular, to determine whether physical fatigue had any effect on RPE as assessed by the R protocol. The P protocol was included because it was another method of assessing the subject's perception of exercise intensity. The results from both protocols confirmed that when exercise at a constant intensity (in this case, treadmill running) is prolonged, fatigue develops, RPE values increase progressively, and there is a characteristic upward drift in heart rate (17).

Since the subjects were allowed a 20-min rest between the end of the treadmill run and the start of the second cycle exercise, there was some recovery in the fatigue score (5.7 to 9.4; compare Tables 4 and 5). However, this was still less than the score before the first cycle exercise (9.4 vs. 12.3; see Table 5). The effect on RPE and power output for cycle exercise performed before and after the treadmill run was small. The average rise in RPE was only 0.7 units, which is considerably less than the increase of 3.0 units observed between the first and last bout of treadmill running (Table 4). The decrease in power output for the P protocol was correspondingly small. If sleep deprivation increased the subject's susceptibility to physical fatigue in Experiment II, as suggested earlier in this discussion, then the R protocol might have been unaffected by it.

In summary, it appears that, where the exercise is of several minutes' duration, RPE is increased by sleep deprivation and by physical fatigue. Where the exercise period is as short as 30 s, sleep deprivation has no effect and physical fatigue causes very little change in the perception of exercise intensity.

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